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Only in the Heat of the Moment?
A Study of the Relation between Weather and Mortality in Germany[1]

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1. Motivation

One of the channels through which climate change affects human health is the induced shift in the distribution of temperatures (WHO, 2008). This shift proceeds in two ways: average temperatures are rising over the whole globe on the one hand, and on the other hand, extreme weather events and in particular heat waves, occur more often and with higher intensity. Regarding predictions of the German Weather Service, at the end of this century the average number of hot days per year in Germany, when temperatures reach or exceed 30°C, can end up at a level which is twice as high as at the end of the 20th century. The impact of these events is apparently important. According to newspaper articles, the heat wave in 2003, for instance, claimed about 3,500 victims in Germany.

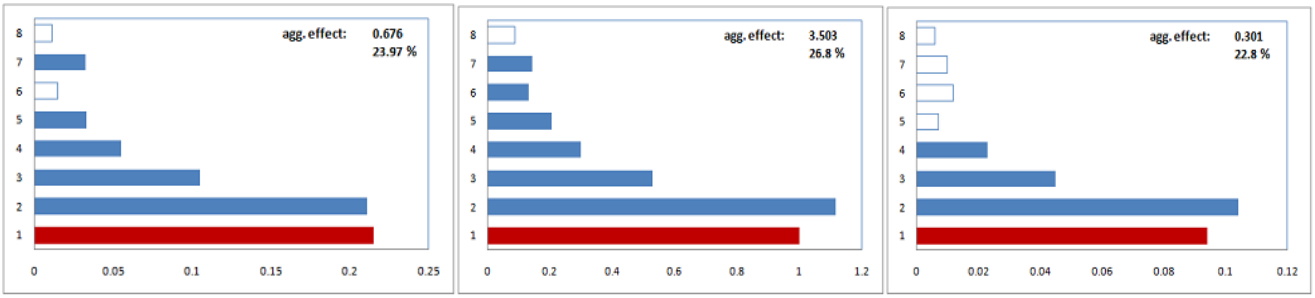
This research focuses on the relation between heat events and the distribution of mortality rates. The main goals are to clarify whether heat immediately leads to an increase in daily mortality and, if so, which term structure of the relation can be singled out. Additionally, possible differences in the heat effect conditioned by the living environment are considered. Using panel data estimation methods, an empirical analysis on daily data of German weather and cause-specific mortality at the country level over the period from 1996 to 2006 was implemented. This summary concentrates on the main results and implications of the analysis and does not contain a detailed description of the methodology, which can be found in the full research piece.

2. The Heat Mortality Nexus

2.1 Immediate Impact of Heat

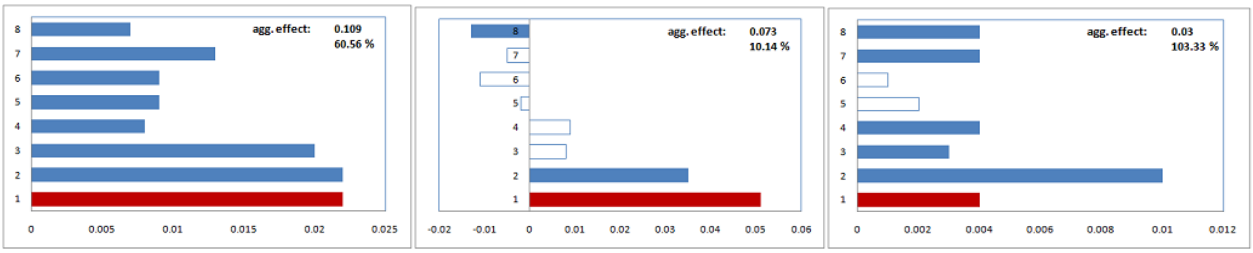
In previous research, one common result has been identified for Western countries: heat immediately leads to an increase in aggregated daily mortality.[2]

Figure 1: Heat-induced mortality per 100,000 inhabitants



(a) All death causes (b) Age 65 years and older (c) Cardiovascular diseases

1 This article is part of a research project in association with Martin Karlsson, Technical University of Darmstadt.
2 See Barnett *et al.* (2010) for an overview of results.



(d) Respiratory diseases (e) Neoplasm (f) Infectious diseases

Notes: Estimated effects of lagged heat events for each cause-specific mortality rate separately. Filled bars stand for significant coefficients. The red bars present immediate mortality increase on the day when heat occurs. Aggregated effects are calculated as the sum of lagged heat coefficients. Percentage change is relative to average mortality on days with moderate temperatures.

Going one step further, effects for specific age groups and causes of death can be analysed separately. It was found that heat-induced mortality varies for different causes. In particular, people in a bad health status, caused by age or chronic diseases, are more affected by heat-induced thermal stress (compare for example to Vaneckova *et al.,* 2008).

The findings of this research validate previous results. We observe that on days of extreme heat all cause mortality for the entire population, as well as for the elderly, increases significantly. The same is valid for death by one of the four specific causes we looked at, namely cardiovascular and respiratory diseases, neoplasms and infectious diseases (see Figure 1).

2.2 The Harvesting Hypothesis

Still an open issue in the literature is the term structure of the relation between heat events and daily mortality. The theory of the Harvesting Hypothesis says that indeed a mortality increase can be observed on hot days, but when a longer time window is considered, mortality will decrease, such that the immediate effect is compensated and the net effect remains zero. This would imply that heat events induce a time displacement, but not a shift in the distribution of mortality rates. Previous research results regarding this hypothesis are not consistent.[3] We implemented the harvesting effect in an empirical framework by including lagged heat events. If observed impacts of previous events on mortality today had been negative, one could have concluded that mortality decreases in a longer time window and thus immediate positive effects are compensated. On the contrary we find that lagged heat events also have a positive impact on mortality today. Figure 1 illustrates the estimated effects of the model specification where seven lagged heat events are included.

In this one week time window, the heat effect remains significantly positive, except for death caused by neoplasms. This result was approved by various specifications of the model considering longer periods and implementing several robustness checks (all can be found in the full research piece). It was determined that the main impact takes place on the day when heat occurs and the first week afterwards. When all causes of mortality are considered, one hot day leads to 0.676 additional deaths per 100,000 inhabitants (0.301 for the elderly), which corresponds to an increase of 23.97 per cent (26.8 per cent respectively) compared to average mortality on days with moderate temperatures. Cause-specific effects have to be interpreted in relation to the respective frequency of occurrence. They where also significantly positive and ranged between 0.03 and 0.301 additional deaths per 100,000 inhabitants. The impact was strongest for mortality caused by respiratory and infectious diseases. Overall, no harvesting effect was found in this study, but we observed in fact a heat-induced upward shift in the mortality distribution, and thus a negative impact on public health.

2.3 The Urban Heat Island Hypothesis

In the last part of the research, heat-induced mortality is estimated conditioned on the living area. As the Urban Heat Island Hypothesis predicts (Clarke, 1972), there should be higher mortality in the cities than in rural environments, since there is a slower decreasing in the night temperatures and thus less possibility for human bodies to recover. Differences in the heat effect depending on the living area were found in several previous studies on Western countries (e.g. Sheridan, 2003). For all causes of mortality as well as for specific causes we observed that the heat-induced mortality increase is significantly larger

[3] Deschenes and Moretti, 2009 and Rey *et al.,* 2007.

in urban than in rural areas, while we had on average equal daytime temperatures during hot days for both country types. In addition, we controlled for other time-varying weather determinants that might differ between cities and rural areas, such that we can detach ourselves from possible other influences on the heat mortality nexus. This result might be an indication that the Urban Heat Island Hypothesis holds true, but an extension of the analysis is necessary in order to analyse whether differences are caused by diverging nighttime temperatures.

3. Conclusions

In this research it was observed that extreme heat leads to an upward shift in the distribution of daily mortality. Estimated effects are stronger when only the population of age 65 years and older is considered. In view of the fact that population ageing is predicted to proceed in the future, our results imply that the overall heat effect might even be underestimated.

From an economic perspective, the estimated health shocks induce welfare losses. In this framework, results should be embedded in a framework of monetary terms. Therefore, we applied the value of €3,345,213 per statistical heat-induced death avoided from Alberini *et al.* (2006). Results are presented in Table 1.

Regarding the entire population, the welfare losses in monetary terms that occur from mortality induced by one additional hot day in Germany have an estimated value of €1,861 million. For sure, this calculation is very rough, but even so, one thing remains clear: meteorological experts predict up to twice as many hot days per year in Germany at the end of this century. Combining this with the value of heat-induced lives lost, the economic relevance of the effect is considerably large.

Table 1: Statistical Value of Lives Lost

Variable	Entire population	Elderly population	Respiratory diseases	Cardiovas-cular diseases	Neoplasm	Infectious diseases
Mortality increase per 100,000 effect in %	0.676 23.97	3.503 26.80	0.109 60.56	0.301 22.80	0.073 10.14	0.03 103.33
Monetary value in m €	1,861	1,113	300	829	201	83

Notes: First row reports estimated heat induced additional deaths, when a period of seven days is considered. Second row includes mortality percentage change of average mortality on temperate days. The last row reports monetary value of lost lives, assuming a value of €3,345,2139 per statistical death avoided. To aggregate the effect per 100,000 inhabitants on the whole of Germany, the relevant population size from the year 2006 of 82,314,906 (9,496,708 for people of age 65 and older) was assumed. Each column includes results of specific death causes.

To reduce these costs, society has to be prepared for forthcoming climate change and its implications. On the one hand, policymakers can take mitigation action, like is done, for example, by the United Nations Framework Convention on Climate Change, which has the goal to jointly stop global warming. On the other hand, adaptation actions can be taken to reduce the intensity of thermal stress on human bodies during heat waves, such that the health implications of climate change are abated. These can be the implementation of heat warning systems, enlightenment of the population on prevention behaviour or hospital action plans during heat waves, to mention only a few. Of particular importance the heat-induced health impact is for the healthcare sector, where several parties will be affected. In particular the health insurance system has to deal with the implications of the changing climate. The observed shift in the distribution of mortality rates is primarily important for life insurances and pension funds. Their payment flows depend on life length and the premium system is built on life tables which are determined

by the long-term distribution of mortality. In general, assumptions about this distribution are based on historical data which could potentially be misleading to the extent that it is distorted by a changing climate.

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